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Discussions

Interactive comment on "Joint State and Parameter Estimation of Two Land Surface Models Using the Ensemble Kalman Filter and Particle Filter" *by* H. Zhang et al.

Anonymous Referee #1

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The manuscript addresses an important issue in soil hydrology: The application of data assimilation methods to real world data, especially when estimating not only states, but also parameters. The authors state to address three main questions: (1) the performance of the data assimilation methods on Land Surface Models with real world data in general, (2) the differences in performance due to different data assimilation methods and (3) difference in performance due to different Land Surface Models. The study finds small differences due to data assimilation methods and large differences based on different Land Surface Models.
These findings can give valuable insight for the applicability of data assimilation methods on Land Surface Models. But, this requires an adequate discussion of the

used measurements, data assimilation methods and finally the results.
I have 3 major comments regarding each of these discussions, which fall short off answering the stated main questions enough. Additionally I have one major comment on the quality of the explanations for employed methods and models.

General comments:

1. Discussion of the used measurements: Since data assimilation combines observations and measurements based on their uncertainties, a good description of these uncertainties can be important for good performance. Because of this, I would appreciate a detailed discussion of the measurements, their uncertainties and the implications of the assumptions made.
Especially discuss the following points:

Page 10, Lines 20-23: " . . . and a soil moisture and soil temperature sensor network (with measurements at 5, 20 and 50cm depth) are installed, amongst others. Soil moisture time series at 41 locations are being recorded."
What kind of soil moisture sensors are installed? Please discuss possible uncertainties in the data.

Page 10, Lines 24-35: "In this work, the Rollesbroich site is modeled as a single point and the data of the soil sensor network are averaged to calculate areal averages of soil moisture content at 5cm, 20cm and 50cm depth."
Please discuss the importance and implications of this assumption. What are the expected impacts of heterogeneity?

Page 29, Figure 3: The figure shows higher water contents closer to the surface. Please mention this and discuss reasons and implications.

Page 11 Lines 34-36: "The soil moisture observation error is assumed to be normally distributed with mean equal to 0 and standard deviation equal to 0.02m3/m3, for both VIC-3L and CLM.“ Please discuss why you assume this uncertainty, especially since it is a mean of 41 values.

Page 11 Lines 33-34: "Precipitation was perturbed were perturbed by multiplicative error N(1,0.1) to represent the uncertainty of measured precipitation at the site.“ Please give a reason for this error. What is the assumed error for evaporation?

2. Discussion of the assimilation methods: Since the methods combine observations and models based on their uncertainties, the representation of the model uncertainties can be important. Please discuss the following points in more detail:

Page 2, Lines 13-15: "This approach allows for joint estimation of the states and parameters while taking into explicit consideration model structural error and forcing data errors (Liu and Gupta, 2007).“ This is correct, but it is not to the point, since the authors later set the model error to zero (see Page 11, Lines 36-37) and hence do not consider model structural errors. Please discuss this.

Page 6, Line 25 (Eq. 25): Please mention that the way R (and y_t^i) is described, you assume uncorrelated measurement errors.

Page 7, Line 25 (Eq. 33): Please describe the implications of employing this method. How does the performance of the filter depend on the choice of initial uncertainty?

Page 9, Line 13. How did you choose the tuning parameter s? How does it influence the performance? Please include the choice of s for the PF and initial uncertainties of the EnKF when comparing different methods.

Page 15 Line 32: You state: "It is not surprising that the EnKF is more efficient and effective than the PF.“ I would follow this statement in case of strictly Gaussian distributions and linear measurement operators. In those cases the EnKF is expected to outperform the PF. Nevertheless, when dealing with non-linear processes that challenge the Gaussian assumption, the better performance is not clear at all.

Page 165 Line 33: You state that EnKF and PF "differ fundamentally in their analysis step“. I would disagree and argue that the analysis step is similar. The only difference is that the EnKF updates it's posterior based on the Gaussian assumption of the distributions, while the PF drops this assumption.

Page 25, Table 1: The EnKF assumes Gaussian distributions. What is the reason that you sample for all but one parameter from an initial uniform distribution? What are the implications for the chosen inflation method?

Page 16, Lines 1-2: You state: "The value of the likelihood does generally not say anything about how close the forecasted variables are to their measured counterparts.“ I disagree, the likelihood yields information about the distance.

3. Discussion of results: Since the results show a wealth of information. I would appreciate a detailed discussion. Especially consider the following points in detail and incorporate them into your conclusion:

Page 29, Figure 3: The large deviations in the Particle Filter might hint at filter inbreeding in the states. You observe the deviation but do not discuss it and actually exclude the possibility of inbreeding by investigating the parameters: "A too narrow spread of ensemble members would lead to filter divergence. For the state augmentation (AUG) and dual estimation (DUAL), the spread of the ensemble members is kept large enough during the whole assimilation period as the ensemble inflation method helped to keep adequate ensemble spread. RRPF and MCMCPF also have enough ensemble spread because of parameter perturbation and MCMCPF resampling.“ (Page 13 Lines 15-19). Please address the question of adequate ensemble spread in the states by actually showing the ensemble of states there.

Page 30 Figure 4: During the calibration period the filter without parameter estimation performs better. Please discuss possible reasons.

Page 31 Figure 5: Parameter b estimated by MCMC shows a large difference to the other methods. But MCMC does perform approximately as well as the other filters (Figure 7, Page 33). Why is there no difference? Please discuss.

Page 32 Figure 6: Initial parameter uncertainties are the same for PF and EnKF but at time 0 the ensemble spreads are different. Please explain.
You only show the two parameters with the least change over time. Give a reason or show the one with the smallest and the one with the largest changes.

Page 34, Figure 8: There is basically no difference for the prediction of the water content whether there are parameters estimated or not. Please discuss why this is the case.

Page 37 Figure 11: You do not show the parameters from the augmented state.

Instead you show parameters derived from those in a non-linear way. Please discuss this.

Figures 7, 8, 12, 13: Especially water content of the top layer can almost not be represented by either model, although improved with state of the art data assimilation methods.
Please discuss this including the representation of the physics in the models and implications of the perfect model assumption.
The difference in the assimilation methods is small. Please discuss if this difference is significant. Do you expect the same results for other applications? What is the influence of specific filter settings on the performance?

4. Please improve the explanations on the Particle Filter and the two LSMs.

Page 7 Line 32 - Page 8 Line 11: I do understand Particle Filters, but the given explanation is not clear. Especially clarify your description of transition and proposal densities.
Page 8 Lines 21-30: You describe SIR and RR. What is the reason to choose RR?
Page 7 Lines 31-32: "The particle filter was first suggested in the research area of object recognition, robotics and target tracking (Arulampalam et al., 2002).“ The PF was actually mentioned earlier (Gordon et al., 1993).

For this study the understanding of the different LSM models is important, since the main difference in performance is attributed to different models. Because of that a good description is necessary. Although I am not an expert on LSMs, I noticed the following:
Page 17, Line 15 (Eq. A2): The equation describes the soil water movement in the top two layers. To me it was not clear if this description is valid for both layers individually.

If so, why is the precipitation P and evaporation E the same?
Page 18, Line 1 (Eq. A7): The dimensions are inconsistent: You add [LT-1], [] and [L]. i_m should be I_m (or is not introduced).
Please also explain the distinction of the cases $P + I < I_m$ and $P + I > I_m$.
Page 19, Lines 18-22: the Richards equation is formulated for a continuum. Please explain the modifications and the implications of applying it to layers. Please give the extent of these layers.

Specific comments:

Page 5, Line 36: "Commonly used data assimilation algorithms are EnKF, PF and variants of them.“ 4D-Var is also commonly used.

Page 6, Line 19: "H [. . .] is the identity matrix if y refers to in-situ ground measurements available at all grid cells.“ This is only the case if the same quantity as the state is observed. Otherwise the quantity has to be transferred. Additionally mention that H has to be linear for the EnKF.

Page 6-7: You do not mention the use of a damping factor (Hendricks Franssen and Kinzelbach, 2008) for the parameters. Is there a specific reason you do not employ it?

Page 25, Table 1: It is not clear which parameters are estimated for each layer individually and which are estimated for the entire profile.

Page 11 Lines 11-12: "The parameters of the other layers were updated with help of the calculated spatial covariances in case of EnKF.“

This statement implies that the parameters were not estimated with the PF? Please clarify.

Page 11 Line 30: "EnKF with state updating only was tested for (2).“
Why did you not test state updating with the PF?

Page 12 Lines 2-10: Why do you need 2 different characterizations of the uncertainty. What is the additional gain by showing NSE?

Page 12 Line 9-10: "A NSE value equal to 1 and RMSE equal to 0 imply a perfect prediction.“ This is wrong. A RMSE equal to the measurement uncertainty is perfect.

Technical corrections:

Page 6, Line 8: "v_{t-1} to model error at time step t“ should be v_t

Page 8, Line 9 (Eq. 35): Sign not printed (displayed as empty square).

Page 9, Lines 6-13 and Page 9, Line 31-Page 10, Line 13: Algorithms are formatted differently.

Page 11 Lines 33: " . . . was perturbed were perturbed . . .“

Page 13, Line 3: "Even although“ should be "even though“?

Page 17, Line 9: Introduce Leaf Area Index, before using the abbreviation LAI.

Page 18, Line 1 (Eq. A7): Maybe choose another letter than I since it could be confused with 1 in the exponent.

Page 18, Line 25: "soil matric potential ψ_i [L]" is actually the matric head. In soil physics the matric head is typically described with h_m, while potentials are described with ψ.

Page 19, Line 23: "Niu (Niu et al.,2007)" should be Niu et al. (2007).

Consistently write D_m, k_s with subscripted characters.

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